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To: Mr. T. T. Goodale Date: August 12, 1981

From: W. E. Claflin, A. C. Lilly, P. Martin

Subject: Studies Relating To The Mechanism Of Dilution Reduction Of Barclay Cigarettes

Over the past six months a mass of data has been collected confirming the fact that humans smoke Barclay cigarettes at significantly lower dilution levels than when smoked on standard testing machines. This, of course, is the basis for the claim that machine tar analysis is not a true indicator of human tar intake.

While the important fact is that dilution does decrease, it is of interest to determine how the Barclay cigarette dilution is lowered by the smoker. The Barclay filter system, by it's unique design, segregates the incoming dilution air from the smoke stream moving thru the filter. It is thus apparent that the smoker must be choking off the air stream in some fashion. There are two main speculations to explain this occurrence. One, and the easiest to visualize, is that the pressure of the smoker's lips presses the tipping paper down into the dilution channels, obstructing the channels thus restricting flow. Certain evidence has been put forth to support this hypothesis, most notably the crimped appearance of the filters after smoking and the use of pressurized holders in smoking machines. The second is that the smoker's lips actually fold over the edge of the filter, thus occluding the ends of the channels and restricting flow. A combination of events can be envisioned in this mechanism; firstly, a straight sealing of the channel with the lip and secondly, or jointly, a folding over of the flexible tipping paper at the end of the groove to act in the manner of a valve. Evidence supporting this hypothesis has also been noted, including video pictures inside the mouth as well as human dilution measurements with stiffened tipping paper or with hollow tubes inserted into the channels to prevent collapse of the tipping paper into the channel. In fact, a study was recently concluded that indicated that a number of smokers obtained a very significant dilution reduction smoking cigarettes with tubes inserted in the filter which allowed only straight sealing of the channels with the lips (Table 1 and Figure 1).

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In practice, a combination of effects is probably true, and most likely the relative contribution of the effects varies from smoker to smoker. In order to test this supposition, a small study was undertaken to quantify the dilution reduction mechanisms of two smokers. Test cigarettes were prepared as shown in Figure 2. The regular Barclay (Figure 2a) was puffed, lit and unlit, to provide baseline data. The smoker's dilution with channels open was obtained with a dental dam holder; the normal smoker's dilution with all effects operating was obtained with the cigarette held in the mouth. The flush tube test cigarette (Figure 2b) provided a measure of the dilution possible when only straight channel blocking was available to the smoker. The recessed tubes (Figure 2c) allowed the smoker to block as in Figure 2b but also to drape the tipping paper over the end of the channel acting as a valve. The difference between the results with cigarettes 2b and 2c then provided a measure of the valving effect only. In reality, both effects are occlusion as they require the lips to fold over the edge of the filter. It can be noted that no matter how much lip pressure is exerted on the surface of the filter in these two cigarettes, no channel closure is possible as the tubes keep the channels open. The tube arrangement in Figure 2d allows the lips to exert pressure for channel closure but no blocking or valving is possible. The following section describes how these effects can be quantified and gives the results obtained on two subjects.

ANALYSIS AND SUMMARY OF RESULTS

Since the mechanisms described above arise from the interaction of the mouth with the cigarette, i.e. an occlusion of the end of the cigarette and an obstruction of the dilution channel along the filter, it should be possible to describe the effects as a fractional change of the original dilution. Thus the dilution remaining after both of these effects occur can be calculated by:

$$\text{Final Dilution} = \text{Starting Dilution} \times (1-\text{Occlusion Factor}) \times (1-\text{Pressure Factor}) \div 1$$

These dilution reduction factors should be essentially independent of each other and will vary from smoker to smoker, and probably from cigarette to cigarette, depending upon the individual lip properties and the smoking characteristics of the cigarette.

The experiments described above were designed to separate the mechanisms and to allow an estimation of the separate reduction factors. The experiments were done on two subjects and the results are shown in Table 2 with both lit and unlit cigarettes. The first row shows the results when the cigarette was held in a dental dam. This eliminates all lip-cigarette interaction and serves as a value of starting dilution. A measurement of dilution under static flow conditions is not a good starting value since it does not account for the individual's puffing characteristics.

The second row shows results with hollow tubes recessed into the dilution channels. This eliminates pressure factors along the filter body and hence can be used to calculate the occlusion reduction factor:

Final Dilution = Starting Dilution x (1-Occlusion Factor) → II

These results are shown in Row 3. The next row shows the dilutions achieved with the hollow rods inserted into the ends of the channels and extending into the mouth. These prevent the lips from blocking the ends of the channels or from forcing the edge of the tipping paper into the channel as the lips try to contour to the cigarette. Thus this allows the calculation of a pressure factor by:

Final Dilution = Starting Dilution x (1-Pressure Factor) → III

and the results are shown in Row 5.

These two effects can be combined to predict an overall dilution reduction by Equation I and the results are shown in Table 2 together with the results obtained when the cigarette was smoked in the lips. It can be seen that the calculation is a good predictor of the final dilution within the dilution variation that can be expected from cigarette to cigarette. It is also apparent that for these two subjects, the occlusion factor is substantially larger than the pressure factor, so it would be predicted that the occlusion of the end of the cigarette, either by straight blocking or a valving action of the tipping paper edge into the channel, is more important than lip pressure along the length of the dilution channel.

It was predicted by a consultant who is an expert on lip anatomy that the valving effect could be very substantial. It is difficult to measure independently since the occlusion factor necessarily includes both blocking and valving. On the postulate that the three effects are independent, Equation I is modified to become:

Final Dilution = Starting Dilution x (1-Blocking Factor) x (1-Valving Factor) x (1-Pressure Factor) → IV

An experiment was done where the hollow tubes extended to the end of the cigarette. This excluded the possibility of both valve and pressure effects and so allows the calculation of the blocking factor. The valving factor can then be derived from Equation IV. Table 3 shows a comparison of these three factors as percentages of the total effect, and it can be seen that there is a lot of variability of the relative percentages from subject to subject and under different conditions. It would appear, however, that the pure blocking effect is the most important, but it should be emphasized that each smoker will use each effect when smoking a cigarette under normal conditons.

/gmm
cc: Mr. Jerome Chapman - Arnold & Porter
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Dr. W. A. Farone
Mr. L. F. Meyer

Attachments

Best regards
Cliff Dilly
Peter Martin

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TABLE 1

HUMAN DILUTION MEASUREMENTS - BARCLAY WITH INSERTED TUBES

JULY 1, 1981

SMOKER #	% DILUTION	
	TIP WITH DENTAL DAM	MOUTH
1	60	32
2	61	22
3	48	34
4	66	37
5	62	16
6	65	53
7	60	32
8	71	42
9	65	47
10	68	35
11	64	11
AVERAGE	63	33

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TABLE 2

EXPERIMENTAL DILUTION RESULTS (%), REDUCTION FACTORS AND PREDICTED DILUTIONS

	Subject 1		Subject 2	
Conditions	Unlit	Lit	Unlit	Lit
Dental Dam	75%	81%	72%	79%
Tubes Recessed	33%	45%	17%	28%
Occlusion Factor	0.56	0.44	0.76	0.65
Tubes Extended	47%	56%	50%	69%
Pressure Factor	0.37	0.31	0.31	0.13
Calculated Mouth Dilution	21%	31%	12%	24%
Actual Mouth Dilution	19%	25%	16%	25%

TABLE 3

RELATIVE DILUTION REDUCTION CONTRIBUTION

	Subject 1		Subject 2	
	Unlit	Lit	Unlit	Lit
Blocking	34.6%	48.1%	59.7%	57.6%
Valving	29.8%	12.7%	14.3%	28.3%
Pressure	35.6%	39.2%	26.0%	14.1%
	100%	100%	100%	100%

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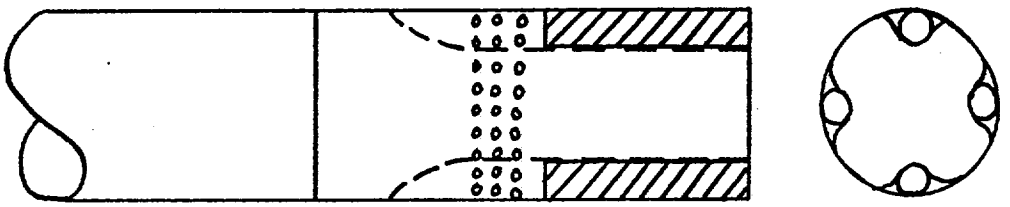
FIGURE 1

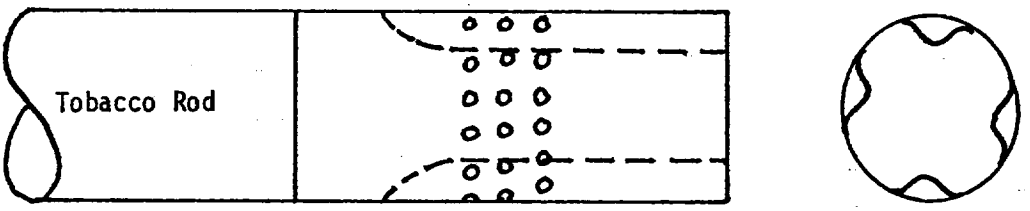
Barclay Filter With Inserted Tubes



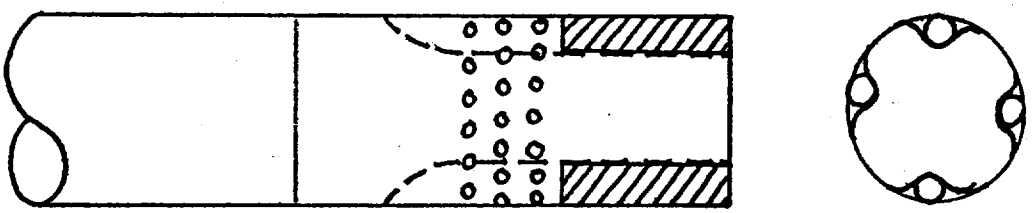
Tube Dimensions: O.D. = .043"
I.D. = .015

FIGURE 2

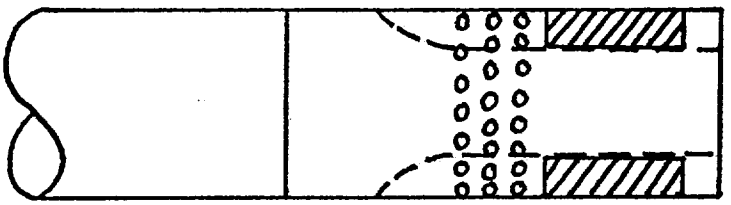
Cigarettes Used In Barclay Dilution Reduction Test



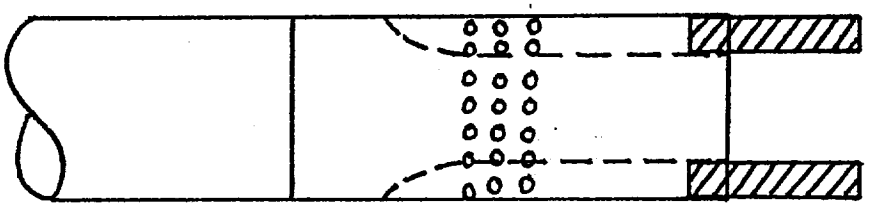
a. As is



b. Flush Tubes



c. Recessed Tubes



d. Extended Tubes

Tube sizes same as Figure 1

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